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(54) Title: SYSTEM AND SCHEME FOR MAXIMUM TRANSITION RUN LENGTH CODES WITH LOCATION DEPENDENT CONSTRAINTS

(57) Abstract

A method and apparatus for encoding data (152) produces a code stream (153) of code words (190, 192, 194) where each code word includes two subsets of code bits. Each subset of code bits is constrained by a different maximum transition run constraint. In an alternative embodiment, the method and apparatus produces a code stream (153) comprised of alternating even bit locations (188) and odd bit locations (186), where the even bit locations are constrained by a different maximum run length constraint than the odd bit locations.

SYSTEM AND SCHEME FOR MAXIMUM TRANSITION RUN LENGTH CODES WITH LOCATION DEPENDENT CONSTRAINTS

FIELD OF THE INVENTION

5   The present invention relates to encoding systems. In particular, the present invention relates to encoding systems in disc drives.

BACKGROUND OF THE INVENTION

          In the field of digital communications,
10   digital information is conveyed from a transmitter to a receiver through a channel. "Channel" is a generalized term that can include many things. For instance, in satellite communication systems, the channel consists of the atmosphere between the earth-bound transmitter
15   and the satellite. In data storage devices, such as magnetic disc drives, the channel includes a storage medium where the signal is stored for some period of time before being delivered to the receiver.

          All channels introduce noise into the signals
20   they convey. To detect and sometimes to correct signal errors caused by this channel noise, the art has developed a large number of coding techniques. These coding techniques convert data words formed of a number of data bits, m, into larger code words formed of a
25   number of code bits, n. The additional bits in the code words permit the detection and sometimes the correction of errors in the signals received from the channel.

          The ratio of the number of data bits to the
30   number of code bits, m/n, is known as the code rate of the code. In general, the ability to detect and correct errors in a received signal increases as the code rate decreases because a lower code rate means a

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greater number of additional bits in the code word.
However, each additional bit added by the encoder
increases the time and energy needed to transmit the
signal through the channel. Thus, to minimize the time
5   and energy needed to send the code, the code rate
should be maximized. A lower code rate results in more
bit crowding, which reduces error rate performance.

In one type of coding, known as non-return-
to-zero-inverse (NRZI), every digital one in a code
10   word is represented by a transition in the transmitted
signal, and every digital zero is represented by a lack
of transitions in the transmitted signal. To allow the
receiver to generate a clock signal using a phase lock
loop and the received signal, the encoded signal is
15   generally limited so that the number of consecutive
zeros is no greater than a maximum number "k". This
kind of code is known as a run-length-limited (RLL)
code with a "k" constraint. It is also known to limit
the number of consecutive ones in an encoded value to
20   limit the effects of inter-symbol interference, which
occurs when consecutive transitions in the transmitted
signal interfere with each other. Such codes are known
as maximum transition run (MTR) codes with an "L"
constraint, where L is the maximum number of
25   consecutive transitions allowed in the channel signal.
For example, to avoid three or more consecutive
transitions, codes with an MTR constraint L=2 can be
designed.

Although MTR codes reduce inter-symbol
30   interference, they eliminate a large number of
available code words making it difficult and sometimes
impossible to implement MTR constraints with high rate
codes. MTR codes improve the bit-error rate by

eliminating the most error prone patterns, which in turn limits the code rate achievable with a given MTR constraint.

The present invention addresses this and other problems, and offers other advantages over the prior art.

SUMMARY OF THE INVENTION

A method and apparatus for encoding data produces a code stream of code words, where each code word includes two subsets of code bits. Each subset of code bits is constrained by a different maximum transition run constraint.

In an alternative embodiment, the method and apparatus produces a code stream comprised of alternating even bit locations and odd bit locations, where the even bit locations are constrained by a different maximum run length constraint than the odd bit locations. In preferred embodiments, even bit locations within the code stream have a maximum transition run constraint of three and odd bit locations within the code stream have a maximum transition run constraint of two.

In further embodiments of the present invention, the code stream is formed through a series of concatenated even and odd code words. Even code words within the code stream have maximum transition run constraints of two for the code words' odd bit locations and three for the code words' even bit locations. For odd code words, the maximum transition run constraints are two for the code words' even bit locations and three for the code words' odd bit locations.

BRIEF DESCRIPTION OF THE DRAWINGS

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FIG. 1 is a plan view of a disc drive.

FIG. 2 is a block diagram of a coding system of the present invention.

FIG. 3 is an organizational layout of an
5   encoded stream showing the numbering and naming
convention used with the present invention.

FIG. 4 is a state diagram for the code of the present invention.

10   DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a plan view of a disc drive 100
that includes a housing with a base plate 102 and a top
cover 104 (sections of top cover 104 are removed for
clarity). Disc drive 100 further includes a disc pack
15   106, which is mounted on a spindle motor (not shown).
Disc pack 106 can include a plurality of individual
discs which are mounted for co-rotation about a central
axis. Each disc surface has an associated head gimbal
assembly (HGA) 112 which is mounted to disc drive 100
20   for communication with the disc surface. Each HGA 112
includes a gimbal and a slider, which carries one or
more read and write heads. Each HGA 112 is supported
by a suspension 118 which is in turn attached to a
track accessing arm 120 known generally as a fixture,
25   of an actuator assembly 122.

Actuator assembly 122 is rotated about a
shaft 126 by a voice coil motor 124, which is
controlled by servo control circuitry within internal
circuit 128. HGA 112 travels in an arcuate path 130
30   between a disc inner diameter 132 and a disc outer
diameter 134. When the head is properly positioned,
write circuitry within internal circuitry 128 encodes
data for storage on the disc and sends an encoded

signal to the head in HGA 112, which writes the
information to the disc. At other times, the read head
in HGA 112 reads stored information from the disc and
provide a recovered signal to detector circuitry and
5   decoder circuitry within internal circuitry 128 to
produce a recovered data signal.

FIG. 2 is a block diagram of a generalized
communication system 148 used with the present
invention. For the disc drive of FIG.1, communication
10   system 148 is formed by internal logic 128, head gimbal
assembly 112 and disc 106. Within communication system
148, an encoder 150 receives data samples 152 and
produces a even and odd code words 153. Even and odd
code words 153 are provided to parallel-to-serial
15   converter 155 in a parallel manner such that all of the
bits of a respective code word are provided to
converter 155 at the same time. Parallel-to-serial
converter 155 converts each parallel code word of even
and odd code words 153 into a serial representation and
20   concatenates the serial representations to produce a
sequence of even and odd bits 154. The sequence of
even and odd bits 154 meets several constraints
discussed further below. Transmitter/channel precoder
156 receives the sequence of even and odd bits 154 and
25   conditions the sequence so that it is optimized for the
type of detector used to recover the signal from the
channel. Transmitter/channel precoder 156 produces
write signal 158, which is provided to channel 160.

Channel 160, which is comprised of a write
30   head, a disc, and a read head when the communication
system is a disc drive, conveys the encoded information
from transmitter/precoder 156 to receiver/detector 162
as a read signal 164. Receiver/detector 162 amplifies

and filters read signal 164 and recovers an encoded
signal from the read signal using one of several known
detection methods. For instance, receiver/detector 162
may use a Viterbi detector, Decision Feedback

5   Equalization (DFE), Fixed-Delay Tree Search with
Decision Feedback (FDTS/DF) or Reduced State Sequence
detection (RSSE). After detecting and amplifying the
signal from channel 160, receiver/detector 162 produces
a recovered sequence of even and odd bits 165, which

10 are provided to serial-to-parallel converter 163. The
sequence of even and odd bits 165 is in a serial format
at the input to serial-to-parallel converter 163.
Serial-to-parallel converter 163 groups the bits into
code words and converts the code words from a serial

15 format to a parallel format. Serial-to-parallel
converter 163 then outputs even and odd code words 166
in a parallel format. The even and odd code words 166
are provided to decoder 168. Decoder 168 uses the
inverse of the coding rules used by encoder 150 and

20 converts the even and odd code words 166 into recovered
data stream 170.

            FIG. 3 shows an organizational layout for a
code stream 178 of bits that is helpful in describing
the numbering and naming system used in connection with

25 the present invention. Code stream 178 is an example
of the type of bit stream that can appear as the
sequence of even and odd bits 154 or the sequence of
even and odd bits 165 of FIG. 2.

            In FIG. 3, the first bit in time is to the

30 far left and later bits in time extend to the right.
Above code stream 178 is number line 176, which assigns
an integer to each bit in code stream 178 based on its
overall location within the entire code stream. Under

the present invention's numbering system, the first bit
is numbered as bit zero, the second bit is bit one and
so on.   Above number line 176 is even/odd line 174,
which provides an "E" designation for each even bit in
5   code stream 178 and an "O" designation for each odd bit
in code stream 178.   The "E" and "O" designation is
vertically aligned with its respective bit in code
stream 178.

Above even/odd line 174 is code-word-bit
10   numbering line 177, which assigns an integer for each
bit corresponding to the bit's location within a code
word.   In the embodiment of FIG. 3, each code word has
9 bit locations numbered 0 to 8.   Above code-word-bit
numbering line 177 is code word even/odd line 175,
15   which provides an "E" designation for each even bit
location in a code word and an "O" designation for each
odd bit location in a code word.

Below code stream 178 is code-word count 180,
which associates a number with each grouping of nine
20   bits in code stream 178.   Thus, the first nine bits
form code word zero, the second nine bits form code
word one, and the third nine bits form code word two.
Vertically aligned with code-word count 180 is even/odd
code word line 182 which provides an "E" designation
25   for each even code word in code stream 178 and an "O"
designation for each odd code word.

Code bits 184, 186, and 188 provide examples
of the numbering and even/odd designations of the
present invention.   Code bit 184 is the fifth bit in
30   code stream 178 and is assigned an overall numerical
value of 4 in number line 176.   Code bit 184 is also
the fifth bit in the first code word, and thus is
assigned a code-word-bit number of 4 in code-word-bit

numbering line 177. Code bit 184 is designated as an
even bit in both even/odd line 174 and code word
even/odd line 175. Code bit 184 is part of the first
code word 190, which is numbered code word zero in code
5   word count 180 and which is designated as an even code
word in even/odd code word line 182.

Bit 186 is the twentieth bit in code stream
178, has a numerical value of nineteen in the code
stream and is considered an odd bit overall as shown in
10 even/odd line 174. Although it is the twentieth bit
overall, bit 186 is only the second bit in code word
194, and as such, has a code-word-bit number of 1 in
code-word-bit numbering line 177. This means that it
is an odd code bit within code word 194, as shown in
15 code word even/odd line 175. Code word 194 has a
numerical value of two and is considered an even code
word.

Bit 188, which is the thirteenth bit in code
stream 178 has an overall numerical value of twelve in
20 numbering line 176 and is considered an even bit
overall. Although bit 188 is the thirteenth bit
overall, it is only the fourth bit in code word 192.
As the fourth bit in code word 192, bit 188 has a code-
word-bit number of 3 in code-word-bit numbering line
25 177, and is considered an odd bit within the code word.
Thus, although bit 188 is an even bit overall, it is
an odd bit within code word 192.

The code of the present invention provides a
rate 8/9 code with location dependent maximum
30 transition run constraints. In one embodiment of this
code, transition runs beginning from odd bit locations
within each code word are limited to two transitions
($L_1=2$) and transition runs starting from even bit

locations are limited to three transitions ($L_2=3$).

With nine-bit code words using binary values
for each bit, there are $2^9=512$ possible code words.
After applying the MTR constraints described above,
5   there are 356 code words that can be used to encode
$2^8=256$ possible data words.

To ensure that invalid patterns do not occur
when code words are concatenated, the 356 code words
are mapped into a two-state system where an individual
10 code word does not appear in more than one state but
can appear twice within the same state.   During
encoding, the two-state coding system is in one of the
two states, state S0 or state S1.   Each data word has
an associated code word and next state value in both
15 state S0 and S1.   The code word is the value produced
by encoder 150 and the next state value determines what
state the two-state system will be in when the next
data word arrives.   The assignment of code words to
particular states and the movement between states is
20 partially controlled by two state definitions.   The
first state definition is that all code words in state
S1 begin with '0'.   Because of this state definition,
any code word may precede state S1 because the
concatenation of any code word with a code word that
25 begins with '0' will not violate the MTR constraint.
The second state definition restricts code words that
precede state S0 to those that end with '0'.   Under
this definition, any code word ending with a '0' may be
used before state S0.

30   Using these state definitions, the mapping
for an 8/9 rate MTR code with local $L_1=2$ and $L_2=3$
constraints can be derived.   Such a mapping is shown in
Table 1 below, where the nine-bit code words are

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represented by two hexadecimal values in the two right most locations and a single binary value in the left most location. The eight bit data words are represented by two hexadecimal values.

5

TABLE 1								
	State 0 (S0)		State 1 (S1)			State 0 (S0)		State 1 (S1)	
Data (Hex)	Codeword	Next State	Codeword	Next State	Data (Hex)	Codeword	Next State	Codeword	Next State
00	101	S1	001	S1	40	121	S1	021	S1
01	103	S1	003	S1	41	123	S1	023	S1
02	105	S1	005	S1	42	125	S1	035	S1
03	107	S1	0B4	S1	43	127	S1	027	S1
04	109	S1	009	S1	44	129	S1	029	S1
05	10B	S1	00B	S1	45	12B	S1	02B	S1
06	10D	S1	00D	S1	46	12D	S1	02D	S1
07	131	S1	031	S1	47	1B1	S1	0B1	S1
08	111	S1	011	S1	48	161	S1	061	S1
09	113	S1	013	S1	49	163	S1	063	S1
0A	115	S1	015	S1	4A	165	S1	065	S1
0B	117	S1	017	S1	4B	167	S1	067	S1
0C	119	S1	019	S1	4C	169	S1	069	S1
0D	11B	S1	01B	S1	4D	16B	S1	06B	S1
0E	11D	S1	01D	S1	4E	16D	S1	06D	S1
0F	1B4	S1	033	S1	4F	1B3	S1	0B3	S1
10	141	S1	041	S1	50	120	S1	020	S1
11	143	S1	043	S1	51	122	S1	022	S1
12	145	S1	045	S1	52	124	S1	024	S1
13	147	S1	047	S1	53	126	S1	026	S1
14	149	S1	049	S1	54	128	S1	028	S1
15	14B	S1	04B	S1	55	12A	S1	02A	S1
16	14D	S1	04D	S1	56	12C	S1	02C	S1
17	135	S1	035	S1	57	1B5	S1	0B5	S1
18	151	S1	051	S1	58	160	S1	060	S1
19	153	S1	053	S1	59	162	S1	062	S1
1A	155	S1	055	S1	5A	164	S1	064	S1
1B	157	S1	057	S1	5B	166	S1	0B6	S1
1C	159	S1	059	S1	5C	168	S1	068	S1
1D	15B	S1	05B	S1	5D	16A	S1	06A	S1
1E	15D	S1	05D	S1	5E	16C	S1	06C	S1
1F	137	S1	037	S1	5F	1B7	S1	0B7	S1
20	181	S1	081	S1	60	1A0	S1	0A0	S1
21	183	S1	083	S1	61	1A2	S1	0A2	S1
22	185	S1	085	S1	62	1A4	S1	0A4	S1

TABLE 1									
	State 0 (S0)		State 1 (S1)			State 0 (S0)		State 1 (S1)	
Data (Hex)	Codeword	Next State	Codeword	Next State	Data (Hex)	Codeword	Next State	Codeword	Next State
23	187	S1	087	S1	63	1A6	S1	0A6	S1
24	189	S1	089	S1	64	1A8	S1	0A8	S1
25	18B	S1	08B	S1	65	1AA	S1	0AA	S1
26	18D	S1	08D	S1	66	1AC	S1	0AC	S1
27	171	S1	071	S1	67	1B2	S1	0B2	S1
28	191	S1	091	S1	68	1A0	S0	0A0	S0
29	193	S1	093	S1	69	1A2	S0	0A2	S0
2A	195	S1	095	S1	6A	1A4	S0	0A4	S0
2B	197	S1	097	S1	6B	1A6	S0	0A6	S0
2C	199	S1	099	S1	6C	1A8	S0	0A8	S0
2D	19B	S1	09B	S1	6D	1AA	S0	0AA	S0
2E	19D	S1	09D	S1	6E	1AC	S0	0AC	S0
2F	173	S1	073	S1	6F	1B2	S0	0B2	S0
30	1C1	S1	0C1	S1	70	120	S0	020	S0
31	1C3	S1	0C3	S1	71	122	S0	022	S0
32	1C5	S1	0C5	S1	72	124	S0	024	S0
33	1AD	S1	0C7	S1	73	126	S0	026	S0
34	1C9	S1	0C9	S1	74	128	S0	028	S0
35	1CB	S1	0CB	S1	75	12A	S0	02A	S0
36	1CD	S1	0CD	S1	76	12C	S0	02C	S0
37	175	S1	075	S1	77	1B4	S0	0B4	S0
38	1D1	S1	0D1	S1	78	160	S0	060	S0
39	1D3	S1	0D3	S1	79	162	S0	062	S0
3A	1D5	S1	0D5	S1	7A	164	S0	064	S0
3B	1D7	S1	0D7	S1	7B	166	S0	066	S0
3C	1D9	S1	0D9	S1	7C	168	S0	068	S0
3D	1DB	S1	0DB	S1	7D	16A	S0	06A	S0
3E	1DD	S1	0DD	S1	7E	16C	S0	06C	S0
3F	177	S1	0AD	S1	7F	1B6	S0	0B6	S0
80	1B0	S1	0B0	S1	C0	1B0	S0	0B0	S0
81	102	S1	002	S1	C1	102	S0	002	S0
82	104	S1	004	S1	C2	104	S0	004	S0
83	106	S1	006	S1	C3	106	S0	006	S0
84	108	S1	008	S1	C4	108	S0	008	S0
85	10A	S1	00A	S1	C5	10A	S0	00A	S0
86	10C	S1	00C	S1	C6	10C	S0	00C	S0
87	130	S1	030	S1	C7	130	S0	030	S0
88	110	S1	010	S1	C8	110	S0	010	S0
89	112	S1	012	S1	C9	112	S0	012	S0
8A	114	S1	014	S1	CA	114	S0	014	S0
8B	116	S1	016	S1	CB	116	S0	016	S0
8C	118	S1	018	S1	CC	118	S0	018	S0
8D	11A	S1	01A	S1	CD	11A	S0	01A	S0

TABLE 1									
	State 0 (S0)		State 1 (S1)			State 0 (S0)		State 1 (S1)	
Data (Hex)	Codeword	Next State	Codeword	Next State	Data (Hex)	Codeword	Next State	Codeword	Next State
8E	11C	S1	0A1	S1	CE	11C	S0	0A3	S1
8F	132	S1	032	S1	CF	132	S0	032	S0
90	140	S1	040	S1	D0	140	S0	040	S0
91	142	S1	042	S1	D1	142	S0	042	S0
92	144	S1	044	S1	D2	144	S0	044	S0
93	146	S1	046	S1	D3	146	S0	046	S0
94	148	S1	048	S1	D4	148	S0	048	S0
95	14A	S1	04A	S1	D5	14A	S0	04A	S0
96	14C	S1	04C	S1	D6	14C	S0	04C	S0
97	134	S1	034	S1	D7	134	S0	034	S0
98	150	S1	050	S1	D8	150	S0	050	S0
99	152	S1	052	S1	D9	152	S0	052	S0
9A	154	S1	054	S1	DA	154	S0	054	S0
9B	156	S1	056	S1	DB	156	S0	056	S0
9C	158	S1	058	S1	DC	158	S0	058	S0
9D	15A	S1	05A	S1	DD	15A	S0	05A	S0
9E	15C	S1	05C	S1	DE	15C	S0	05C	S0
9F	136	S1	036	S1	DF	136	S0	036	S0
A0	180	S1	080	S1	E0	180	S0	080	S0
A1	182	S1	082	S1	E1	182	S0	082	S0
A2	184	S1	084	S1	E2	184	S0	084	S0
A3	186	S1	086	S1	E3	186	S0	086	S0
A4	188	S1	088	S1	E4	188	S0	088	S0
A5	18A	S1	08A	S1	E5	18A	S0	08A	S0
A6	18C	S1	08C	S1	E6	18C	S0	08C	S0
A7	170	S1	0A5	S1	E7	170	S0	0A7	S1
A8	190	S1	090	S1	E8	190	S0	090	S0
A9	192	S1	092	S1	E9	192	S0	092	S0
AA	194	S1	094	S1	EA	194	S0	094	S0
AB	196	S1	096	S1	EB	196	S0	096	S0
AC	198	S1	098	S1	EC	198	S0	098	S0
AD	19A	S1	09A	S1	ED	19A	S0	09A	S0
AE	19C	S1	09C	S1	EE	19C	S0	09C	S0
AF	172	S1	072	S1	EF	172	S0	072	S0
B0	1A1	S1	0C0	S1	F0	1A3	S1	0C0	S0
B1	1C2	S1	0C2	S1	F1	1C2	S0	0C2	S0
B2	1C4	S1	0C4	S1	F2	1C4	S0	0C4	S0
B3	1C6	S1	0C6	S1	F3	1C6	S0	0C6	S0
B4	1C8	S1	0C8	S1	F4	1C8	S0	0C8	S0
B5	1CA	S1	0CA	S1	F5	1CA	S0	0CA	S0
B6	1CC	S1	0A9	S1	F6	1CC	S0	0AB	S1
B7	174	S1	074	S1	F7	174	S0	074	S0
B8	1D0	S1	0D0	S1	F8	1D0	S0	0D0	S0

TABLE 1									
	State 0 (S0)		State 1 (S1)			State 0 (S0)		State 1 (S1)	
Data (Hex)	Codeword	Next State	Codeword	Next State	Data (Hex)	Codeword	Next State	Codeword	Next State
B9	1D2	S1	0D2	S1	F9	1D2	S0	0D2	S0
BA	1D4	S1	0D4	S1	FA	1D4	S0	0D4	S0
BB	1D6	S1	0D6	S1	FB	1D6	S0	0D6	S0
BC	1D8	S1	0D8	S1	FC	1D8	S0	0D8	S0
BD	1DA	S1	0DA	S1	FD	1DA	S0	0DA	S0
BE	1A5	S1	0DC	S1	FE	1A7	S1	0DC	S0
BF	176	S1	076	S1	FF	176	S0	076	S0

Because a single code word can occur twice
within a given state for two different data words, the
decoder must determine the state of the next code word
to decode the present code word. For example, if code
5   word "120" is received, and the decoder is in state S0,
the code word represent either data word "50" or data
word "70". The decoder must determine which state the
next code word belongs to before it can determine what
10   data word the code word "120" represents. If the next
code word is from state S0, "70" will be the decoded
output, otherwise "50" will be the decoded output.

In order for a detector to identify code
words that violate the MTR constraint and thus contain
15   an error, the detector must keep track of whether it
has an odd numbered code word or an even numbered code
word. Since there are nine bits in each code words, if
the decoder did not keep track of even and odd code
words but merely kept track of whether it had an even
20   or odd bit overall, the tenth received bit would
considered an odd bit overall. However, since the
tenth received bit is the first bit of the second code
word, it is an even bit within that code word.
Therefore, in order to properly track even and odd
25   locations within code words, the detector must be

complex enough to keep track of even and odd code words in addition to keeping track of even and odd bits within code words.

5   To reduce this complexity, the present invention provides an alternate rate 8/9 code word mapping. In this alternate mapping, even code words are constrained in the same manner as described above such that transition runs beginning from odd bit locations are limited to two transitions ($L_1=2$) and

10   transition runs beginning from even bit locations are limited to three transitions ($L_2=3$). However, odd code words under this alternate mapping have different localized MTR constraints. Specifically, for odd code words, transition runs beginning from odd bit locations

15   are limited to three transitions ($L_1=3$) and transition runs beginning from even bit locations are limited to two transitions ($L_2=2$). By interleaving code words that use these two different sets of constraints, an MTR code is formed that provides universal MTR

20   constraints of two for odd bit locations and three for even bit locations counting from the beginning of the code stream. Thus, the decoder does not have to keep track of whether the current code word is in an even temporal location or an odd temporal location. It only

25   has to keep track of the overall temporal location of the bits.

        Of the possible 512 nine-bit code words, 317 meet the $L_1=3$ and $L_2=2$ MTR constraint. To ensure proper concatenation, the 317 code words that meet this

30   constraint and the 356 code words that meet the $L_1=2$ and $L_2=3$ MTR constraint are divided into four states each, forming a total of eight states. The four · states for the code words having an MTR constraint of

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three for even code words (L_2=3) and two for odd code words (L_1=2) are denoted as states S0, S2, S4 and S6. The four states for the code words satisfying the MTR constraint of three for odd positions (L_1=3) and two for even positions (L_2=2) are denoted as states S1, S2, S5 and S7.

The four states for one group of code words shares common state definitions with the four states for the other group of code words. Code words in states S0 or S1 can begin with any two bits including "11" so code words preceding state S0 or state S1 must end with "0". The code words in state S2 or state S3 may only begin with "10" so code words preceding state S2 or state S3 must end with "00" or "01". Code words in states S4, S5, S6, and S7 only begin with "0" so any code word may proceed these states.

Given these state definitions, the 356 code words that satisfy the MTR constraint of three for temporally even bit positions and two for temporally odd bit positions are divided between states S0, S2, S4, and S6. Similarly, the 317 code words that satisfy the MTR constraint of three for temporally odd bit positions and two for temporally even bit positions are divided between states S1, S3, S5, and S7. Note that many code words satisfy both constraints and thus are found in more than one state. However, code words found in even numbered states such as S0, S2, S4, or S6 are not found in another even numbered state. Similarly, a single code word does not appear in two different odd numbered states (S1, S3, S5, or S7). The code words found in an even numbered state, however, can be found in an odd numbered state. In addition, code words may be repeated within a state.

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To realize the universal MTR constraint of two for odd bit positions and three for even bit positions over the entire encoded signal, the next state for any even numbered state, states S0, S2, S4 or

5   S6, must be an odd numbered state, states S1, S3, S5, or S7. Similarly, the next state for any odd numbered state, must be an even numbered state.

An encoding/decoding table for a code based on these eight states is shown in Table 2 below. In

10 Table 2, "NS" in the headers indicates the next state for the encoder/decoder. The code words of these tables are described in a modified hexadecimal format where the two right-most character locations are described by hexadecimal characters and the left-most

15 character location is described by a binary value.

Table 2																
	State 0 (S0)		State 1 (S1)		State 2 (S2)		State 3 (S3)		State 4 (S4)		State 5 (S5)		State 6 (S6)		State 7 (S7)	
Data	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS
00	1C2	S1	1AE	S0	100	S1	100	S0	028	S1	028	S0	00C	S1	00C	S0
01	182	S1	182	S0	102	S1	102	S0	02A	S1	02A	S0	002	S1	002	S0
02	184	S1	184	S0	104	S1	104	S0	02C	S1	02C	S0	004	S1	004	S0
03	186	S1	186	S0	106	S1	106	S0	04C	S1	04C	S0	006	S1	006	S0
04	188	S1	188	S0	108	S1	108	S0	0A8	S1	0A8	S0	008	S1	008	S0
05	18A	S1	18A	S0	10A	S1	10A	S0	0AA	S1	0AA	S0	00A	S1	00A	S0
06	18C	S1	18C	S0	10C	S1	10C	S0	0AC	S1	0AC	S0	020	S1	020	S0
07	190	S1	190	S0	110	S1	110	S0	08C	S1	08C	S0	022	S1	022	S0
08	192	S1	192	S0	112	S1	112	S0	060	S1	060	S0	010	S1	010	S0
09	194	S1	194	S0	114	S1	114	S0	062	S1	062	S0	012	S1	012	S0
0A	196	S1	196	S0	116	S1	116	S0	064	S1	064	S0	014	S1	014	S0
0B	198	S1	198	S0	118	S1	118	S0	068	S1	068	S0	016	S1	016	S0
0C	19A	S1	19A	S0	11A	S1	11A	S0	06A	S1	06A	S0	018	S1	018	S0
0D	1A0	S1	1A0	S0	120	S1	120	S0	06C	S1	06C	S0	01A	S1	01A	S0
0E	1A2	S1	1A2	S0	122	S1	122	S0	05C	S1	02E	S0	024	S1	024	S0
0F	1A4	S1	1A4	S0	124	S1	124	S0	072	S1	03A	S0	026	S1	026	S0
10	1A6	S1	1A6	S0	126	S1	126	S0	074	S1	04E	S0	040	S1	040	S0
11	1A8	S1	1A8	S0	128	S1	128	S0	076	S1	06E	S0	042	S1	042	S0
12	1AA	S1	1AA	S0	12A	S1	12A	S0	09C	S1	08E	S0	044	S1	044	S0

	State 0 (S0)		State 1 (S1)		State 2 (S2)		State 3 (S3)		State 4 (S4)		State 5 (S5)		State 6 (S6)		State 7 (S7)	
Data	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS
13	1AC	S1	1AC	S0	12C	S1	12C	S0	0DC	S1	0AE	S0	046	S1	046	S0
14	1B0	S1	1B0	S0	130	S1	130	S0	075	S1	0B8	S0	048	S1	048	S0
15	1B2	S1	1B2	S0	132	S1	132	S0	075	S3	0BA	S0	04A	S1	04A	S0
16	1B4	S1	1B4	S0	134	S1	134	S0	09D	S3	0CE	S0	030	S1	030	S0
17	1B6	S1	1B6	S0	136	S1	136	S0	073	S5	0E2	S0	032	S1	032	S0
18	19D	S3	039	S2	140	S1	140	S0	075	S5	0E4	S0	050	S1	050	S0
19	1C1	S3	0B9	S2	142	S1	142	S0	09D	S5	0E6	S0	052	S1	052	S0
1A	1C5	S3	0E1	S2	144	S1	144	S0	073	S7	0E8	S0	054	S1	054	S0
1B	1C9	S3	0E5	S2	146	S1	146	S0	075	S7	0EA	S0	056	S1	056	S0
1C	1CD	S3	0E9	S2	148	S1	148	S0	09D	S7	0EC	S0	058	S1	058	S0
1D	1D1	S3	0ED	S2	14A	S1	14A	S0	025	S5	025	S4	05A	S1	05A	S0
1E	1D5	S3	139	S2	14C	S1	14C	S0	029	S5	029	S4	034	S1	034	S0
1F	1D9	S3	1B9	S2	150	S1	150	S0	02D	S5	02D	S4	036	S1	036	S0
20	19D	S5	039	S4	152	S1	152	S0	031	S5	031	S4	080	S1	080	S0
21	1C1	S5	0B9	S4	154	S1	154	S0	035	S5	035	S4	082	S1	082	S0
22	1C5	S5	0E1	S4	156	S1	156	S0	041	S5	041	S4	084	S1	084	S0
23	1C9	S5	0E5	S4	158	S1	158	S0	045	S5	045	S4	086	S1	086	S0
24	1CD	S5	0E9	S4	15A	S1	15A	S0	049	S5	049	S4	088	S1	088	S0
25	1D1	S5	0ED	S4	160	S1	160	S0	04D	S5	04D	S4	08A	S1	08A	S0
26	1D5	S5	139	S4	162	S1	162	S0	051	S5	051	S4	0A0	S1	0A0	S0
27	1D9	S5	1B9	S4	164	S1	164	S0	055	S5	055	S4	0A2	S1	0A2	S0
28	19D	S7	039	S6	166	S1	166	S0	059	S5	059	S4	090	S1	090	S0
29	1C1	S7	0B9	S6	168	S1	168	S0	061	S5	061	S4	092	S1	092	S0
2A	1C5	S7	0E1	S6	16A	S1	16A	S0	065	S5	065	S4	094	S1	094	S0
2B	1C9	S7	0E5	S6	16C	S1	16C	S0	069	S5	069	S4	096	S1	096	S0
2C	1CD	S7	0E9	S6	15C	S1	13A	S0	06D	S5	06D	S4	098	S1	098	S0
2D	1D1	S7	0ED	S6	15C	S3	13A	S2	081	S5	081	S4	09A	S1	09A	S0
2E	1D5	S7	139	S6	15C	S5	13A	S4	085	S5	085	S4	0A4	S1	0A4	S0
2F	1D9	S7	1B9	S6	15C	S7	13A	S6	089	S5	089	S4	0A6	S1	0A6	S0
30	183	S5	183	S4	170	S1	10E	S0	059	S7	059	S6	0C0	S1	0C0	S0
31	18B	S5	18B	S4	172	S1	12E	S0	061	S7	061	S6	0C2	S1	0C2	S0
32	193	S5	193	S4	174	S1	14E	S0	065	S7	065	S6	0C4	S1	0C4	S0
33	19B	S5	19B	S4	176	S1	16E	S0	069	S7	069	S6	0C6	S1	0C6	S0
34	1A3	S5	1A3	S4	170	S3	10E	S2	06D	S7	06D	S6	0C8	S1	0C8	S0
35	1AB	S5	1AB	S4	172	S3	12E	S2	081	S7	081	S6	0CA	S1	0CA	S0
36	1B3	S5	1B3	S4	174	S3	14E	S2	085	S7	085	S6	0B0	S1	0B0	S0
37	1DB	S5	1BB	S4	176	S3	16E	S2	089	S7	089	S6	0B2	S1	0B2	S0
38	183	S7	183	S6	170	S5	10E	S4	025	S7	025	S6	0D0	S1	0D0	S0
39	18B	S7	18B	S6	172	S5	12E	S4	029	S7	029	S6	0D2	S1	0D2	S0

Table 2

	State 0 (S0)		State 1 (S1)		State 2 (S2)		State 3 (S3)		State 4 (S4)		State 5 (S5)		State 6 (S6)		State 7 (S7)	
Data	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS
3A	193	S7	193	S6	174	S5	14E	S4	02D	S7	02D	S6	0D4	S1	0D4	S0
3B	19B	S7	19B	S6	176	S5	16E	S4	0DD	S3	0E3	S2	0D6	S1	0D6	S0
3C	1A3	S7	1A3	S6	170	S7	10E	S6	0DD	S5	0E3	S4	0D8	S1	0D8	S0
3D	1AB	S7	1AB	S6	172	S7	12E	S6	08D	S3	08D	S2	0DA	S1	0DA	S0
3E	1B3	S7	1B3	S6	174	S7	14E	S6	08D	S5	08D	S4	0B4	S1	0B4	S0
3F	1DB	S7	1BB	S6	176	S7	16E	S6	08D	S7	08D	S6	0B6	S1	0B6	S0
40	1C2	S3	1AE	S2	100	S3	100	S2	028	S3	028	S2	00C	S3	00C	S2
41	182	S3	182	S2	102	S3	102	S2	02A	S3	02A	S2	002	S3	002	S2
42	184	S3	184	S2	104	S3	104	S2	02C	S3	02C	S2	004	S3	004	S2
43	186	S3	186	S2	106	S3	106	S2	04C	S3	04C	S2	006	S3	006	S2
44	188	S3	188	S2	108	S3	108	S2	0A8	S3	0A8	S2	008	S3	008	S2
45	18A	S3	18A	S2	10A	S3	10A	S2	0AA	S3	0AA	S2	00A	S3	00A	S2
46	18C	S3	18C	S2	10C	S3	10C	S2	0AC	S3	0AC	S2	020	S3	020	S2
47	190	S3	190	S2	110	S3	110	S2	08C	S3	08C	S2	022	S3	022	S2
48	192	S3	192	S2	112	S3	112	S2	060	S3	060	S2	010	S3	010	S2
49	194	S3	194	S2	114	S3	114	S2	062	S3	062	S2	012	S3	012	S2
4A	196	S3	196	S2	116	S3	116	S2	064	S3	064	S2	014	S3	014	S2
4B	198	S3	198	S2	118	S3	118	S2	068	S3	068	S2	016	S3	016	S2
4C	19A	S3	19A	S2	11A	S3	11A	S2	06A	S3	06A	S2	018	S3	018	S2
4D	1A0	S3	1A0	S2	120	S3	120	S2	06C	S3	06C	S2	01A	S3	01A	S2
4E	1A2	S3	1A2	S2	122	S3	122	S2	05C	S3	02E	S2	024	S3	024	S2
4F	1A4	S3	1A4	S2	124	S3	124	S2	072	S3	03A	S2	026	S3	026	S2
50	1A6	S3	1A6	S2	126	S3	126	S2	074	S3	04E	S2	040	S3	040	S2
51	1A8	S3	1A8	S2	128	S3	128	S2	076	S3	06E	S2	042	S3	042	S2
52	1AA	S3	1AA	S2	12A	S3	12A	S2	09C	S3	08E	S2	044	S3	044	S2
53	1AC	S3	1AC	S2	12C	S3	12C	S2	0DC	S3	0AE	S2	046	S3	046	S2
54	1B0	S3	1B0	S2	130	S3	130	S2	01D	S3	0B8	S2	048	S3	048	S2
55	1B2	S3	1B2	S2	132	S3	132	S2	05D	S3	0BA	S2	04A	S3	04A	S2
56	1B4	S3	1B4	S2	134	S3	134	S2	071	S3	0CE	S2	030	S3	030	S2
57	1B6	S3	1B6	S2	136	S3	136	S2	01D	S5	0E2	S2	032	S3	032	S2
58	181	S3	181	S2	140	S3	140	S2	05D	S5	0E4	S2	050	S3	050	S2
59	185	S3	185	S2	142	S3	142	S2	071	S5	0E6	S2	052	S3	052	S2
5A	189	S3	189	S2	144	S3	144	S2	01D	S7	0E8	S2	054	S3	054	S2
5B	18D	S3	18D	S2	146	S3	146	S2	05D	S7	0EA	S2	056	S3	056	S2
5C	191	S3	191	S2	148	S3	148	S2	071	S7	0EC	S2	058	S3	058	S2
5D	195	S3	195	S2	14A	S3	14A	S2	025	S3	025	S2	05A	S3	05A	S2
5E	1A1	S3	1A1	S2	14C	S3	14C	S2	029	S3	029	S2	034	S3	034	S2
5F	1A5	S3	1A5	S2	150	S3	150	S2	02D	S3	02D	S2	036	S3	036	S2
60	1A9	S3	1A9	S2	152	S3	152	S2	031	S3	031	S2	080	S3	080	S2

Table 2

	State 0 (S0)		State 1 (S1)		State 2 (S2)		State 3 (S3)		State 4 (S4)		State 5 (S5)		State 6 (S6)		State 7 (S7)	
Data	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS
61	1AD	S3	1AD	S2	154	S3	154	S2	035	S3	035	S2	082	S3	082	S2
62	1B1	S3	1B1	S2	156	S3	156	S2	041	S3	041	S2	084	S3	084	S2
63	1B5	S3	1B5	S2	158	S3	158	S2	045	S3	045	S2	086	S3	086	S2
64	11D	S3	103	S2	15A	S3	15A	S2	049	S3	049	S2	088	S3	088	S2
65	15D	S3	10B	S2	160	S3	160	S2	04D	S3	04D	S2	08A	S3	08A	S2
66	171	S3	113	S2	162	S3	162	S2	051	S3	051	S2	0A0	S3	0A0	S2
67	173	S3	11B	S2	164	S3	164	S2	055	S3	055	S2	0A2	S3	0A2	S2
68	11D	S5	123	S2	166	S3	166	S2	059	S3	059	S2	090	S3	090	S2
69	15D	S5	12B	S2	168	S3	168	S2	061	S3	061	S2	092	S3	092	S2
6A	171	S5	143	S2	16A	S3	16A	S2	065	S3	065	S2	094	S3	094	S2
6B	173	S5	14B	S2	16C	S3	16C	S2	069	S3	069	S2	096	S3	096	S2
6C	11D	S7	153	S2	111	S3	111	S2	06D	S3	06D	S2	098	S3	098	S2
6D	15D	S7	15B	S2	115	S3	115	S2	081	S3	081	S2	09A	S3	09A	S2
6E	171	S7	163	S2	119	S3	119	S2	085	S3	085	S2	0A4	S3	0A4	S2
6F	173	S7	16B	S2	121	S3	121	S2	089	S3	089	S2	0A6	S3	0A6	S2
70	091	S3	091	S2	125	S3	125	S2	031	S7	031	S6	0C0	S3	0C0	S2
71	095	S3	095	S2	129	S3	129	S2	035	S7	035	S6	0C2	S3	0C2	S2
72	099	S3	099	S2	12D	S3	12D	S2	041	S7	041	S6	0C4	S3	0C4	S2
73	0A1	S3	0A1	S2	131	S3	131	S2	045	S7	045	S6	0C6	S3	0C6	S2
74	0A5	S3	0A5	S2	135	S3	135	S2	049	S7	049	S6	0C8	S3	0C8	S2
75	0A9	S3	0A9	S2	141	S3	141	S2	04D	S7	04D	S6	0CA	S3	0CA	S2
76	0AD	S3	0AD	S2	145	S3	145	S2	051	S7	051	S6	0B0	S3	0B0	S2
77	0B1	S3	0B1	S2	149	S3	149	S2	055	S7	055	S6	0B2	S3	0B2	S2
78	0B5	S3	0B5	S2	14D	S3	14D	S2	001	S3	001	S2	0D0	S3	0D0	S2
79	0C1	S3	0C1	S2	151	S3	151	S2	005	S3	005	S2	0D2	S3	0D2	S2
7A	0C5	S3	0C5	S2	155	S3	155	S2	009	S3	009	S2	0D4	S3	0D4	S2
7B	0C9	S3	0C9	S2	159	S3	159	S2	00D	S3	00D	S2	0D6	S3	0D6	S2
7C	0CD	S3	0CD	S2	161	S3	161	S2	011	S3	011	S2	0D8	S3	0D8	S2
7D	0D1	S3	0D1	S2	165	S3	165	S2	015	S3	015	S2	0DA	S3	0DA	S2
7E	0D5	S3	0D5	S2	169	S3	169	S2	019	S3	019	S2	0B4	S3	0B4	S2
7F	0D9	S3	0D9	S2	16D	S3	16D	S2	021	S3	021	S2	0B6	S3	0B6	S2
80	1C2	S5	1AE	S4	11C	S1	138	S0	028	S5	028	S4	00C	S5	00C	S4
81	182	S5	182	S4	102	S5	102	S4	02A	S5	02A	S4	002	S5	002	S4
82	184	S5	184	S4	104	S5	104	S4	02C	S5	02C	S4	004	S5	004	S4
83	186	S5	186	S4	106	S5	106	S4	04C	S5	04C	S4	006	S5	006	S4
84	188	S5	188	S4	108	S5	108	S4	0A8	S5	0A8	S4	008	S5	008	S4
85	18A	S5	18A	S4	10A	S5	10A	S4	0AA	S5	0AA	S4	00A	S5	00A	S4
86	18C	S5	18C	S4	10C	S5	10C	S4	0AC	S5	0AC	S4	020	S5	020	S4
87	190	S5	190	S4	110	S5	110	S4	08C	S5	08C	S4	022	S5	022	S4

	State 0 (S0)		State 1 (S1)		State 2 (S2)		State 3 (S3)		State 4 (S4)		State 5 (S5)		State 6 (S6)		State 7 (S7)	
Data	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS
88	192	S5	192	S4	112	S5	112	S4	060	S5	060	S4	010	S5	010	S4
89	194	S5	194	S4	114	S5	114	S4	062	S5	062	S4	012	S5	012	S4
8A	196	S5	196	S4	116	S5	116	S4	064	S5	064	S4	014	S5	014	S4
8B	198	S5	198	S4	118	S5	118	S4	068	S5	068	S4	016	S5	016	S4
8C	19A	S5	19A	S4	11A	S5	11A	S4	06A	S5	06A	S4	018	S5	018	S4
8D	1A0	S5	1A0	S4	120	S5	120	S4	06C	S5	06C	S4	01A	S5	01A	S4
8E	1A2	S5	1A2	S4	122	S5	122	S4	05C	S5	02E	S4	024	S5	024	S4
8F	1A4	S5	1A4	S4	124	S5	124	S4	072	S5	03A	S4	026	S5	026	S4
90	1A6	S5	1A6	S4	126	S5	126	S4	074	S5	04E	S4	040	S5	040	S4
91	1A8	S5	1A8	S4	128	S5	128	S4	076	S5	06E	S4	042	S5	042	S4
92	1AA	S5	1AA	S4	12A	S5	12A	S4	09C	S5	08E	S4	044	S5	044	S4
93	1AC	S5	1AC	S4	12C	S5	12C	S4	0DC	S5	0AE	S4	046	S5	046	S4
94	1B0	S5	1B0	S4	130	S5	130	S4	017	S5	0B8	S4	048	S5	048	S4
95	1B2	S5	1B2	S4	132	S5	132	S4	027	S5	0BA	S4	04A	S5	04A	S4
96	1B4	S5	1B4	S4	134	S5	134	S4	037	S5	0CE	S4	030	S5	030	S4
97	1B6	S5	1B6	S4	136	S5	136	S4	047	S5	0E2	S4	032	S5	032	S4
98	181	S5	181	S4	11C	S5	138	S4	057	S5	0E4	S4	050	S5	050	S4
99	185	S5	185	S4	142	S5	142	S4	067	S5	0E6	S4	052	S5	052	S4
9A	189	S5	189	S4	144	S5	144	S4	087	S5	0E8	S4	054	S5	054	S4
9B	18D	S5	18D	S4	146	S5	146	S4	097	S5	0EA	S4	056	S5	056	S4
9C	191	S5	191	S4	148	S5	148	S4	0A7	S5	0EC	S4	058	S5	058	S4
9D	195	S5	195	S4	14A	S5	14A	S4	0B7	S5	03B	S4	05A	S5	05A	S4
9E	1A1	S5	1A1	S4	14C	S5	14C	S4	0C7	S5	0BB	S4	034	S5	034	S4
9F	1A5	S5	1A5	S4	150	S5	150	S4	0D7	S5	0EB	S4	036	S5	036	S4
A0	1A9	S5	1A9	S4	152	S5	152	S4	003	S5	003	S4	080	S5	080	S4
A1	1AD	S5	1AD	S4	154	S5	154	S4	00B	S5	00B	S4	082	S5	082	S4
A2	1B1	S5	1B1	S4	156	S5	156	S4	013	S5	013	S4	084	S5	084	S4
A3	1B5	S5	1B5	S4	158	S5	158	S4	01B	S5	01B	S4	086	S5	086	S4
A4	103	S5	103	S4	15A	S5	15A	S4	023	S5	023	S4	088	S5	088	S4
A5	10B	S5	10B	S4	160	S5	160	S4	02B	S5	02B	S4	08A	S5	08A	S4
A6	113	S5	113	S4	162	S5	162	S4	033	S5	033	S4	0A0	S5	0A0	S4
A7	11B	S5	11B	S4	164	S5	164	S4	043	S5	043	S4	0A2	S5	0A2	S4
A8	123	S5	123	S4	166	S5	166	S4	04B	S5	04B	S4	090	S5	090	S4
A9	12B	S5	12B	S4	168	S5	168	S4	053	S5	053	S4	092	S5	092	S4
AA	143	S5	143	S4	16A	S5	16A	S4	05B	S5	05B	S4	094	S5	094	S4
AB	14B	S5	14B	S4	16C	S5	16C	S4	063	S5	063	S4	096	S5	096	S4
AC	153	S5	153	S4	111	S5	111	S4	06B	S5	06B	S4	098	S5	098	S4
AD	15B	S5	15B	S4	115	S5	115	S4	083	S5	083	S4	09A	S5	09A	S4
AE	163	S5	163	S4	119	S5	119	S4	08B	S5	08B	S4	0A4	S5	0A4	S4

	State 0 (S0)		State 1 (S1)		State 2 (S2)		State 3 (S3)		State 4 (S4)		State 5 (S5)		State 6 (S6)		State 7 (S7)	
Data	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS
AF	16B	S5	16B	S4	121	S5	121	S4	093	S5	093	S4	0A6	S5	0A6	S4
B0	091	S5	091	S4	125	S5	125	S4	09B	S5	09B	S4	0C0	S5	0C0	S4
B1	095	S5	095	S4	129	S5	129	S4	0A3	S5	0A3	S4	0C2	S5	0C2	S4
B2	099	S5	099	S4	12D	S5	12D	S4	0AB	S5	0AB	S4	0C4	S5	0C4	S4
B3	0A1	S5	0A1	S4	131	S5	131	S4	0B3	S5	0B3	S4	0C6	S5	0C6	S4
B4	0A5	S5	0A5	S4	135	S5	135	S4	0C3	S5	0C3	S4	0C8	S5	0C8	S4
B5	0A9	S5	0A9	S4	141	S5	141	S4	0CB	S5	0CB	S4	0CA	S5	0CA	S4
B6	0AD	S5	0AD	S4	145	S5	145	S4	0D3	S5	0D3	S4	0B0	S5	0B0	S4
B7	0B1	S5	0B1	S4	149	S5	149	S4	0DB	S5	0DB	S4	0B2	S5	0B2	S4
B8	0B5	S5	0B5	S4	14D	S5	14D	S4	001	S5	001	S4	0D0	S5	0D0	S4
B9	0C1	S5	0C1	S4	151	S5	151	S4	005	S5	005	S4	0D2	S5	0D2	S4
BA	0C5	S5	0C5	S4	155	S5	155	S4	009	S5	009	S4	0D4	S5	0D4	S4
BB	0C9	S5	0C9	S4	159	S5	159	S4	00D	S5	00D	S4	0D6	S5	0D6	S4
BC	0CD	S5	0CD	S4	161	S5	161	S4	011	S5	011	S4	0D8	S5	0D8	S4
BD	0D1	S5	0D1	S4	165	S5	165	S4	015	S5	015	S4	0DA	S5	0DA	S4
BE	0D5	S5	0D5	S4	169	S5	169	S4	019	S5	019	S4	0B4	S5	0B4	S4
BF	0D9	S5	0D9	S4	16D	S5	16D	S4	021	S5	021	S4	0B6	S5	0B6	S4
C0	1C2	S7	1AE	S6	11C	S3	138	S2	028	S7	028	S6	00C	S7	00C	S6
C1	182	S7	182	S6	102	S7	102	S6	02A	S7	02A	S6	002	S7	002	S6
C2	184	S7	184	S6	104	S7	104	S6	02C	S7	02C	S6	004	S7	004	S6
C3	186	S7	186	S6	106	S7	106	S6	04C	S7	04C	S6	006	S7	006	S6
C4	188	S7	188	S6	108	S7	108	S6	0A8	S7	0A8	S6	008	S7	008	S6
C5	18A	S7	18A	S6	10A	S7	10A	S6	0AA	S7	0AA	S6	00A	S7	00A	S6
C6	18C	S7	18C	S6	10C	S7	10C	S6	0AC	S7	0AC	S6	020	S7	020	S6
C7	190	S7	190	S6	110	S7	110	S6	08C	S7	08C	S6	022	S7	022	S6
C8	192	S7	192	S6	112	S7	112	S6	060	S7	060	S6	010	S7	010	S6
C9	194	S7	194	S6	114	S7	114	S6	062	S7	062	S6	012	S7	012	S6
CA	196	S7	196	S6	116	S7	116	S6	064	S7	064	S6	014	S7	014	S6
CB	198	S7	198	S6	118	S7	118	S6	068	S7	068	S6	016	S7	016	S6
CC	19A	S7	19A	S6	11A	S7	11A	S6	06A	S7	06A	S6	018	S7	018	S6
CD	1A0	S7	1A0	S6	120	S7	120	S6	06C	S7	06C	S6	01A	S7	01A	S6
CE	1A2	S7	1A2	S6	122	S7	122	S6	05C	S7	02E	S6	024	S7	024	S6
CF	1A4	S7	1A4	S6	124	S7	124	S6	072	S7	03A	S6	026	S7	026	S6
D0	1A6	S7	1A6	S6	126	S7	126	S6	074	S7	04E	S6	040	S7	040	S6
D1	1A8	S7	1A8	S6	128	S7	128	S6	076	S7	06E	S6	042	S7	042	S6
D2	1AA	S7	1AA	S6	12A	S7	12A	S6	09C	S7	08E	S6	044	S7	044	S6
D3	1AC	S7	1AC	S6	12C	S7	12C	S6	0DC	S7	0AE	S6	046	S7	046	S6
D4	1B0	S7	1B0	S6	130	S7	130	S6	017	S7	0B8	S6	048	S7	048	S6
D5	1B2	S7	1B2	S6	132	S7	132	S6	027	S7	0BA	S6	04A	S7	04A	S6

Table 2																
	State 0 (S0)		State 1 (S1)		State 2 (S2)		State 3 (S3)		State 4 (S4)		State 5 (S5)		State 6 (S6)		State 7 (S7)	
Data	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS
D6	1B4	S7	1B4	S6	134	S7	134	S6	037	S7	0CE	S6	030	S7	030	S6
D7	1B6	S7	1B6	S6	136	S7	136	S6	047	S7	0E2	S6	032	S7	032	S6
D8	181	S7	181	S6	11C	S7	138	S6	057	S7	0E4	S6	050	S7	050	S6
D9	185	S7	185	S6	142	S7	142	S6	067	S7	0E6	S6	052	S7	052	S6
DA	189	S7	189	S6	144	S7	144	S6	087	S7	0E8	S6	054	S7	054	S6
DB	18D	S7	18D	S6	146	S7	146	S6	097	S7	0EA	S6	056	S7	056	S6
DC	191	S7	191	S6	148	S7	148	S6	0A7	S7	0EC	S6	058	S7	058	S6
DD	195	S7	195	S6	14A	S7	14A	S6	0B7	S7	03B	S6	05A	S7	05A	S6
DE	1A1	S7	1A1	S6	14C	S7	14C	S6	0C7	S7	0BB	S6	034	S7	034	S6
DF	1A5	S7	1A5	S6	150	S7	150	S6	0D7	S7	0EB	S6	036	S7	036	S6
E0	1A9	S7	1A9	S6	152	S7	152	S6	003	S7	003	S6	080	S7	080	S6
E1	1AD	S7	1AD	S6	154	S7	154	S6	00B	S7	00B	S6	082	S7	082	S6
E2	1B1	S7	1B1	S6	156	S7	156	S6	013	S7	013	S6	084	S7	084	S6
E3	1B5	S7	1B5	S6	158	S7	158	S6	01B	S7	01B	S6	086	S7	086	S6
E4	103	S7	103	S6	15A	S7	15A	S6	023	S7	023	S6	088	S7	088	S6
E5	10B	S7	10B	S6	160	S7	160	S6	02B	S7	02B	S6	08A	S7	08A	S6
E6	113	S7	113	S6	162	S7	162	S6	033	S7	033	S6	0A0	S7	0A0	S6
E7	11B	S7	11B	S6	164	S7	164	S6	043	S7	043	S6	0A2	S7	0A2	S6
E8	123	S7	123	S6	166	S7	166	S6	04B	S7	04B	S6	090	S7	090	S6
E9	12B	S7	12B	S6	168	S7	168	S6	053	S7	053	S6	092	S7	092	S6
EA	143	S7	143	S6	16A	S7	16A	S6	05B	S7	05B	S6	094	S7	094	S6
EB	14B	S7	14B	S6	16C	S7	16C	S6	063	S7	063	S6	096	S7	096	S6
EC	153	S7	153	S6	111	S7	111	S6	06B	S7	06B	S6	098	S7	098	S6
ED	15B	S7	15B	S6	115	S7	115	S6	083	S7	083	S6	09A	S7	09A	S6
EE	163	S7	163	S6	119	S7	119	S6	08B	S7	08B	S6	0A4	S7	0A4	S6
EF	16B	S7	16B	S6	121	S7	121	S6	093	S7	093	S6	0A6	S7	0A6	S6
F0	091	S7	091	S6	125	S7	125	S6	09B	S7	09B	S6	0C0	S7	0C0	S6
F1	095	S7	095	S6	129	S7	129	S6	0A3	S7	0A3	S6	0C2	S7	0C2	S6
F2	099	S7	099	S6	12D	S7	12D	S6	0AB	S7	0AB	S6	0C4	S7	0C4	S6
F3	0A1	S7	0A1	S6	131	S7	131	S6	0B3	S7	0B3	S6	0C6	S7	0C6	S6
F4	0A5	S7	0A5	S6	135	S7	135	S6	0C3	S7	0C3	S6	0C8	S7	0C8	S6
F5	0A9	S7	0A9	S6	141	S7	141	S6	0CB	S7	0CB	S6	0CA	S7	0CA	S6
F6	0AD	S7	0AD	S6	145	S7	145	S6	0D3	S7	0D3	S6	0B0	S7	0B0	S6
F7	0B1	S7	0B1	S6	149	S7	149	S6	0DB	S7	0DB	S6	0B2	S7	0B2	S6
F8	0B5	S7	0B5	S6	14D	S7	14D	S6	001	S7	001	S6	0D0	S7	0D0	S6
F9	0C1	S7	0C1	S6	151	S7	151	S6	005	S7	005	S6	0D2	S7	0D2	S6
FA	0C5	S7	0C5	S6	155	S7	155	S6	009	S7	009	S6	0D4	S7	0D4	S6
FB	0C9	S7	0C9	S6	159	S7	159	S6	00D	S7	00D	S6	0D6	S7	0D6	S6
FC	0CD	S7	0CD	S6	161	S7	161	S6	011	S7	011	S6	0D8	S7	0D8	S6

Table 2																
	State 0 (S0)		State 1 (S1)		State 2 (S2)		State 3 (S3)		State 4 (S4)		State 5 (S5)		State 6 (S6)		State 7 (S7)	
Data	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS	Code	NS
FD	0D1	S7	0D1	S6	165	S7	165	S6	015	S7	015	S6	0DA	S7	0DA	S6
FE	0D5	S7	0D5	S6	169	S7	169	S6	019	S7	019	S6	0B4	S7	0B4	S6
FF	0D9	S7	0D9	S6	16D	S7	16D	S6	021	S7	021	S6	0B6	S7	0B6	S6

In designing encoding/decoding Tables 1 and 2, undesirable patterns or long-run patterns with small Euclidean distances are avoided. For example, patterns of repeating tribits, "11101110..." are eliminated. In addition, patterns with long runs of "11001100..." are eliminated as these patterns may force the detector to keep a long memory length. Thus, not all of the 317 possible code words that meet the MTR constraint of two for even bit locations and three for odd bit locations appear in the tables and not all of the 356 code words that satisfy the MTR constraint of three for even bit locations and two for odd bit locations appear in the tables.

FIG. 4 shows a state diagram for the present invention's universal MTR code of three for even bit locations and two for odd bit locations. State 200 represents the initial state of the encoder/decoder, which is an even bit location. If the bit associated with state 200 is '0', the code moves to state 201, which is an odd bit location. If the bit associated with state 201 is '0', the code returns to state 200. If the associated bit is '1', the code advances to state 202.

State 202 is associated with an even bit location and if that bit location contains a '0', the code returns to state 201. If the bit location

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contains a '1', the code moves to state 203, which is associated with an odd bit location. Since state 203 only occurs after two consecutive ones beginning from an odd bit location, the bit associated with state 203

5   must be '0', causing the code to return to state 200.

If the bit associated with state 200 is '1', the code goes to state 205, which is associated with an odd bit location. If the value of the bit associated with state 205 is '0', the code returns to state 200.

10   If the value of the bit associated with state 205 is '1', the code moves to state 206, which is associated with an even location. A '0' in the even bit location of state 206 moves the code to state 201. A '1' in the even bit location associated with state 206 moves the

15   code to state 207. Since state 207 is associated with three consecutive ones beginning from an even bit location, the MTR constraint of three for even bit locations requires that the bit associated with the odd location of state 207 be '0' and the code returns to

20   state 200.

In summary, the present invention provides a method and apparatus for producing a code stream 158. The coding system includes an encoder 150 capable of converting data values 152 into a series of code

25   symbols 154 in alternating even 188 and odd 186 locations, such that fewer than a first maximum transition run limit of consecutive same first code symbols start from any even bit location 188 and fewer than a second number of consecutive same first symbols

30   start from any odd bit location 186. The coding system further includes a transmitter 156 coupled to encoder 150 and to channel 160 and capable of transmitting an encoded signal based on the series of code symbols 154.

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It is to be understood that even though numerous characteristics and advantages of various embodiments of the present invention have been set forth in the foregoing description, together with

5   details of the structure and function of various embodiments of the invention, this disclosure is illustrative only, and changes may be made in detail, especially in matters of structure and arrangement of parts within the principles of the present invention to

10   the full extent indicated by the broad general meaning of the terms in which the appended claims are expressed. For example, the particular elements may vary depending on the particular application for the coding method and apparatus while maintaining

15   substantially the same functionality without departing from the scope and spirit of the present invention. In addition, although the preferred embodiment described herein is directed to a coding system for a disc drive, it will be appreciated by those skilled in the art that

20   the teachings of the present invention can be applied to other systems, like satellite communications or cellular phone systems, without departing from the scope and spirit of the present invention.

WHAT IS CLAIMED IS:

1.   A disc drive for performing data operations
      relative to a rotating disc, the disc drive
      comprising:
      (a) a transducer assembly which transfers
           signals representative of information
           between the disc and a channel device; and
      (b) code means, coupled to the transducer
           assembly, for producing a code stream of
           code words from an input stream of bits from
           the channel device, each code word
           comprising at least two subsets of code
           bits, each subset of code bits constrained
           by a different maximum transition run
           constraint.

2.   The disc drive of claim 1 wherein a first subset
      of code bits are code bits that occur in even bit
      locations within a code word and a second subset
      of code bits are code bits that occur in odd bit
      locations with a code word.

3.   The disc drive of claim 2 wherein the maximum
      transition run constraint of the first subset of
      code bits is two and the maximum transition run
      constraint of the second subset of code bits is
      three.

4.   The disc drive of claim 2 wherein each code word
      comprises an odd number of code bits.

5.   The disc drive of claim 2 wherein the code means
      treats as invalid a concatenation of code words

that individually meet the maximum transition run
constraint if the concatenation violates the
maximum transition run constraint for at least
one bit in one of the code words.

6.   The disc drive of claim 2 wherein groups of_eight
        bits from the input stream of bits are encoded as
        nine symbols of encoded data.

7.   A disc drive for performing data operations
        relative to a rotating disc, the disc drive
        comprising:
        (a) a transducer assembly which transfers
             signals representative of information
             between the disc and a channel device; and
        (b) code means, coupled to the transducer, for
             producing a code stream from an input stream
             of bits from the channel device of
             alternating even bit locations and odd bit
             locations, the even bit locations
             constrained by a different maximum
             transition run constraint than the odd bit
             locations.

8.   The disc drive of claim 7 wherein the code stream
        comprises at least one code word with an odd
        number of bits.

9.   The disc drive of claim 7 wherein the code stream
        is comprised of alternating first code words and
        second code words, the first code words
        comprising alternating first-word even-bit
        locations and first-word odd-bit locations and
        starting with a first-word even-bit location, the

second code words comprising alternating second-
word even-bit locations and second-word odd-bit
locations and starting with a second-word even-
bit location, the first-word even-bit locations
being constrained by a different maximum
transition run constraint than the second-word
even-bit locations.

10.   The disc drive of claim 9 wherein the first-word
       odd-bit locations are constrained by a different
       maximum transition run constraint than the
       second-word odd-bit locations.

11.   The disc drive of claim 9 wherein the first-word
       even-bit locations are constrained by the same
       maximum transition run constraint as the second-
       word odd-bit locations.

12.   A method of selecting code words for a coding
       system, the method comprising steps of:
       (a)   forming code words, each code word having
              fewer than a first maximum transition run
              limit of consecutive symbols that begin from
              even numbered positions within the
              respective code word and having fewer than a
              second maximum transition run limit of
              consecutive symbols that begin from odd
              numbered positions within the respective
              code word, the first number being different
              from the second number;
       (b)   dividing code words into at least two
              subsets of code words;   and

(c)   assigning a next state value to each code
        word indicating the subset from which the
        next code word is to be selected.

13.   The method of claim 12 wherein the subsets and
        the next state values are chosen so that even
        numbered positions within any code word of two
        concatenated code words do not exceed the first
        maximum transition run limit and so that odd
        numbered positions within any code word of two
        concatenated code words do not exceed the second
        maximum transition run limit.

14.   The method of claim 13 wherein the first maximum
        transition run limit is three and the second
        maximum transition run limit is two.

15.   The method of claim 13 wherein each code word is
        nine symbols long.

16.   A method of selecting code words for a coding
        system, the method comprising steps of:
        (a)   forming a set of first code words, each
                first code word having fewer than a first
                maximum transition run limit of consecutive
                symbols that begin from even numbered
                positions within the respective code word
                and having fewer than a second maximum
                transition run limit of consecutive symbols
                that begin from odd numbered positions
                within the respective code word, the first
                maximum transition run limit being different
                from the second maximum transition run
                limit;

(b)   forming a set of second code words, each
       second code word having fewer than the
       second maximum transition run limit of
       consecutive symbols that begin from even
       numbered positions within the respective
       code word and having fewer than the first
       maximum transition run limit of consecutive
       symbols that begin from odd numbered
       positions within the respective code word;

(c)   dividing the sets of first and second code
       words into at least four subsets of code
       words; and

(d)   assigning a next state value to each code
       word indicating the subset from which the
       next code word is to be selected.

17.   The method of claim 16 wherein the next state
       value for a second code word causes a first code
       word to be selected next.

18.   The method of claim 16 further comprising a
       constraining step wherein the operations of the
       dividing step (c) and the assigning step (e) are
       constrained so that after concatenation of code
       words several conditions are met, including:

       (i) a string of more than the first maximum
            transition run limit of consecutive symbols
            does not begin from an even numbered position
            within any first code word;

       (ii) a string of more than the first maximum
            transition run limit of consecutive symbols
            does not begin from an odd numbered position
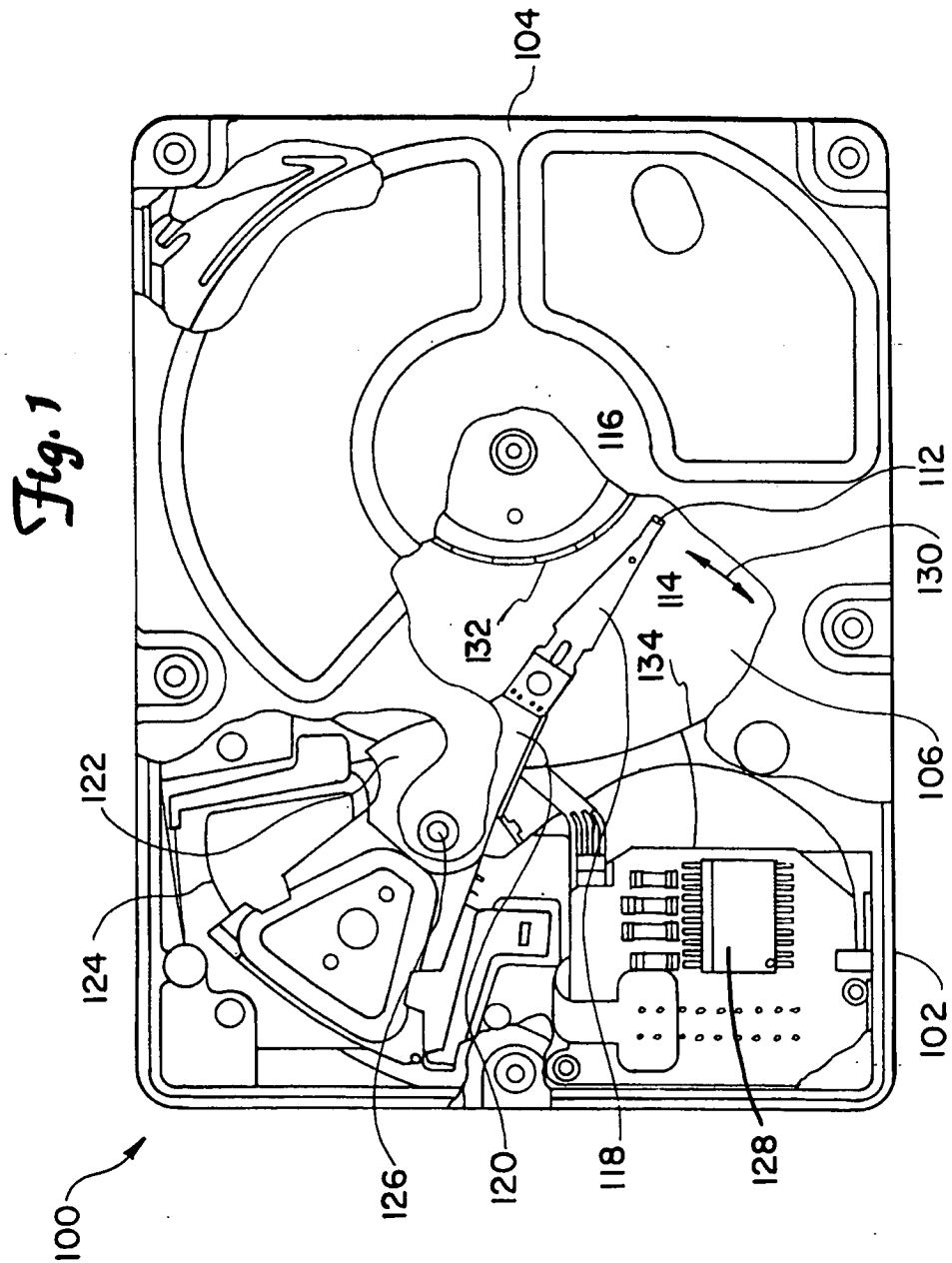   within any second code word;

      (iii) a string of more than the second maximum
           transition run limit of consecutive symbols
           does not begin from an odd numbered position
           within any first code word; and

      (iv) a string of more than the second maximum
           transition run limit of consecutive symbols
           does not begin from an even numbered position
           within any second code word.

19. A coding system for passing encoded signals
    through a channel, the coding system comprising:

    (a) an encoder, capable of converting data
        values into a series of code values having
        alternating even and odd code symbol
        locations, such that fewer than a first
        number of consecutive same code symbols
        start from even code symbol locations in a
        code value and fewer than a second number of
        consecutive same code symbols start from odd
        code symbol locations in a code value; and

    (b) a transmitter, coupled to the encoder and
        the channel and capable of transmitting an
        encoded signal based on the series of code
        symbols.

20. The coding system of claim 19 wherein each code
    value has an odd number of symbols.

21. A coding system for passing encoded signals
    through a channel, the coding system comprising:

    (a) an encoder, capable of converting data
        values into an alternating series of first
        code values and second code values, the
        first code values having alternating first-

code even symbol locations and first-code
odd symbol locations, the second code values
having alternating second-code even symbol
locations and second-code odd symbol
locations, the encoder converting the data
values such that:

(a)(i) fewer than a first maximum transition
       run limit of consecutive same code
       symbols start from first-code even
       symbol locations;

(a)(ii)   fewer than the first maximum
       transition run limit of consecutive
       same code symbols start from second-
       code odd symbol locations;

(a)(iii) fewer than a second maximum
       transition run limit of consecutive
       same code symbols start from first-
       code odd symbol locations; and

(a)(iv)   fewer than the second maximum
       transition run limit of consecutive
       same code symbols start from second-
       code even symbol locations, the first
       number of consecutive same code
       symbols different from the second
       number of consecutive same code
       symbols; and

(b) a transmitter, coupled to the encoder and
     the channel and capable of transmitting an
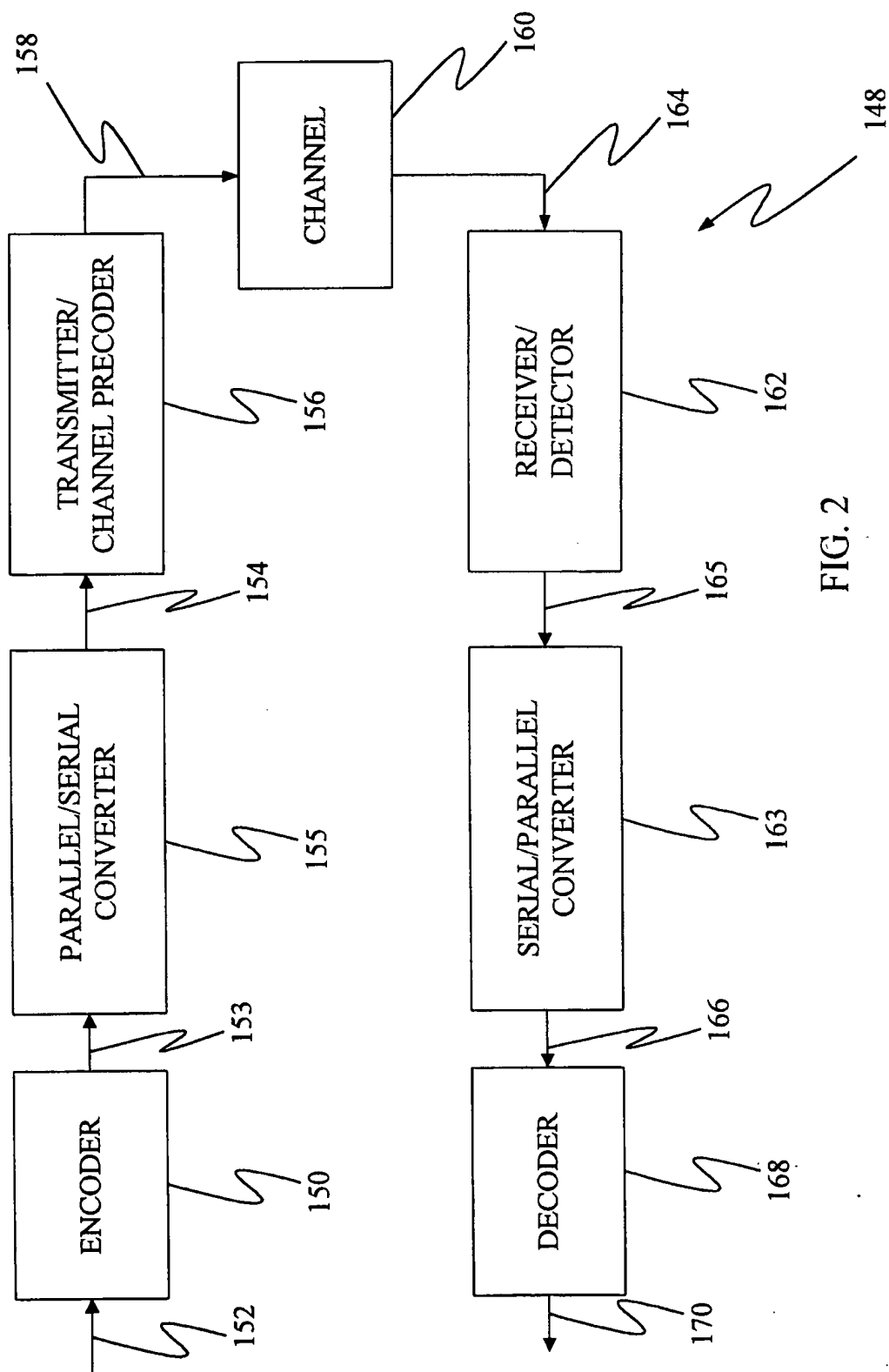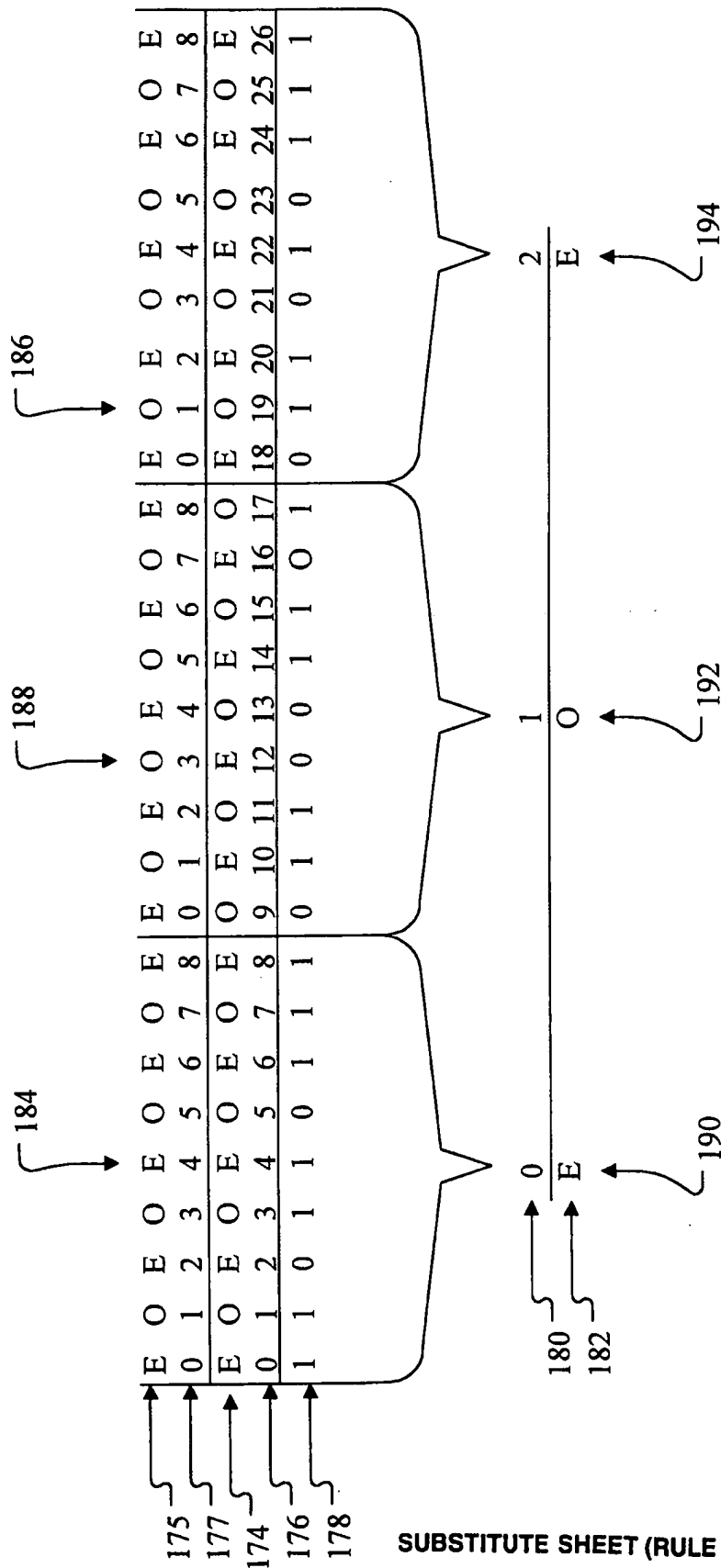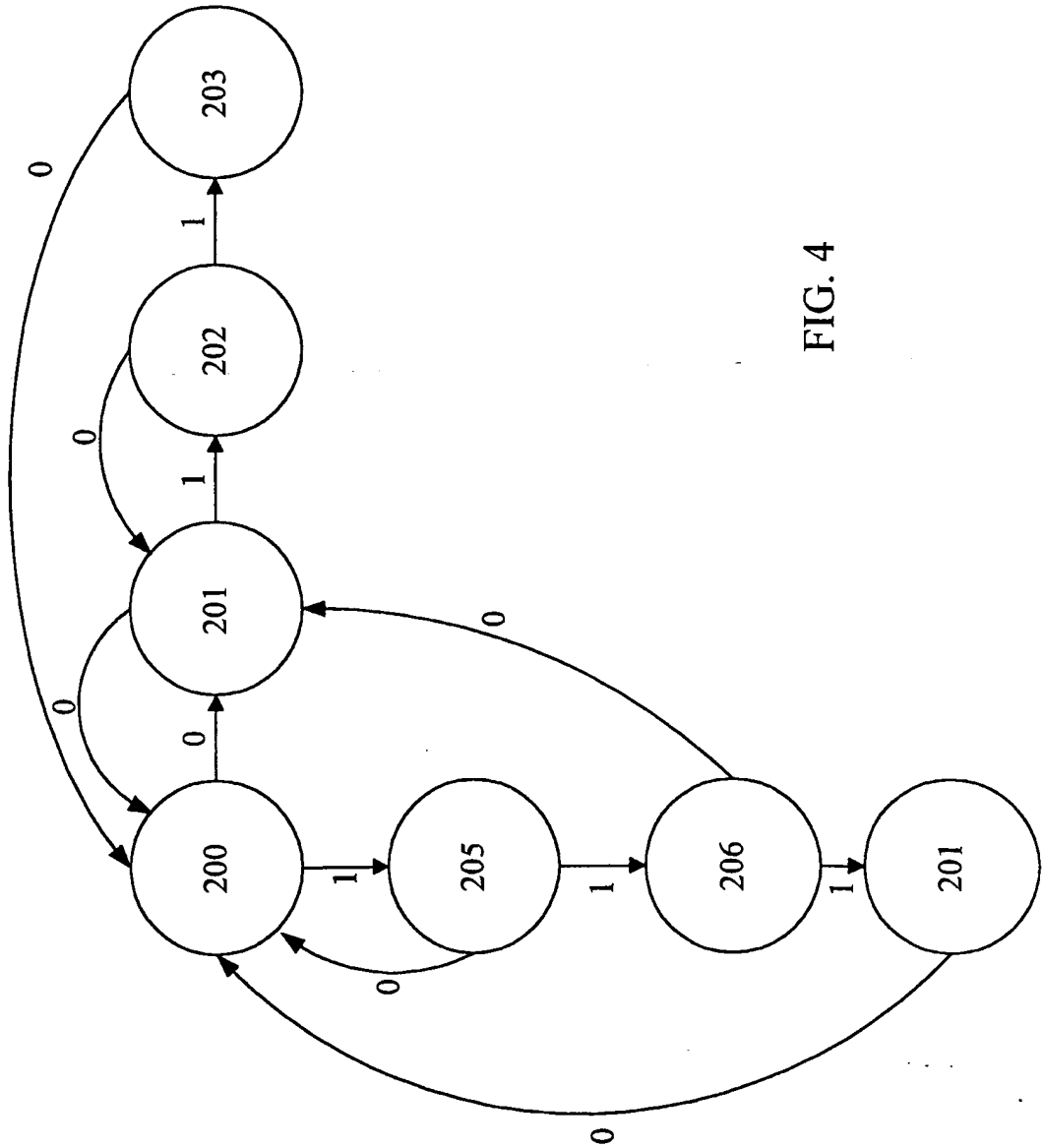   encoded signal based on the series of code
     symbols.

Fig. 1

FIG. 2

FIG. 3

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FIG. 4